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A DIGITAL COMMAND SYSTEM
FOR SATELLITES

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SUMMARY

Present methods of commanding satellites have employed elementary tone-actuated systems, capable of relaying one or two switching functions. A six bit digital command system, with error rejection features and capable of relaying twenty switching functions, has been designed and built. This system may be expanded to include satellite addresses and can be enlarged to eight or ten bits to provide 70 or 252 commands with good error rejection features.

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II

CONTENTS

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INTRODUCTION

A system is proposed herein for transmitting commands to artificial satellites. As late as January 1961, the methods used by the Goddard Space Flight Center have utilized elementary tone-actuated systems; these were adequate for relaying one or two switching commands to the satellite. The Gamma Ray Astronomy Satellite required ten commands, and a tone system was developed by the Army Ballistic Missile Agency (ABMA) to accomplish this. The ABMA system utilizes seven tones and requires a 15 kc bandwidth. The legally available audio frequency range is 3 kc for the lower of the two command frequencies, and 7.5 kc for the higher. A reasonable separation of audio frequencies, considering the customary single tuned filter used in satellites, would be 10 percent, which would permit approximately 25 command frequencies in the wider channel command band. The Orbiting Solar Observatory has reserved seven tones; in addition, the Swept Frequency Topside Sounder (Canada) has reserved seven tones, the Atmospheric Structure Satellite three tones, and the Fixed Frequency Ionosphere Topside Sounder Satellite may require seven tones. Therefore, virtually all the tones have been reserved. Future satellites will have to be scheduled for joint command frequency use at the risk of suffering or causing unscheduled command functions, and additional RF channels must be provided; or a more versatile coding system must be developed.

Another limitation of the tone system is the 20 to 30 db signal-to-noise ratio requirement imposed by the designers. The system described herein is a digital one permitting twenty commands in its simplest form and capable of working at a postdetection signal-to-noise ratio of approximately one to one.

The digital command system can be easily enlarged to provide 70 or more commands. The technique used to minimize errors consists of making the code words from an equal

1

number of zeros and ones. All possible combinations of three zeros and three ones are used in the simplest system to provide twenty commands; four zeros and ones will provide 70 commands. A three by three satellite decoder system can be built in a six-inch-diameter cylinder, two inches long, and operated on approximately 70 milliwatts at 6 volts dc.

The satellite identification problem could be solved by using a separate turn-on tone; this, however, would tend to reduce the signal-to-noise ratio advantage of the digital system, since a signal-to-noise ratio of 20 to 30 db might be required for error-free turn-on of the system. A possible alternate approach would be to turn on the satellite by a digital code made up of 4 zeros and 2 ones or vice versa.

This identification code could be built into the satellite with very few additional parts and would provide turn-on command with a probability of error intermediate between a simple parity check and the n by n coding. The ground station encoder would have a rectangular wave output which could be used to modulate a subcarrier or to amplitude modulate the transmitter directly. Directly modulating the transmitter requires less bandwidth for the command function and thus permits the relatively short command time of 160 milliseconds on the 6-kc-bandwidth command channel. The disadvantage of direct AM operation is the lack of AGC quieting compared to subcarrier AM operation.

DESCRIPTION OF THE PROTOTYPE SYSTEM

The three by three coder provides twenty separate commands coded in digital form. The decoder accepts the commands and causes an output on one of twenty leads. Each command consists of eight time intervals of 4 milliseconds each. The first interval will be blank; the second interval contains the sync pulse of three milliseconds duration; and the following six intervals contain the binary digits of the code. The ones are 2 milliseconds in duration, and the zeros are one millisecond long.

For the purpose of increasing system reliability, each command is repeated five times, and one correctly received command will cause the system to function properly. The requirement could be changed to require that a preselected number of the five transmissions be correct before the system is actuated; however, this would require adding storage registers and sensing networks to the present satellite system. The code, consisting of a six bit word containing only three zeros and three ones, contains within itself a degree of error recognition. A single error in transmission is automatically detected and rejected since it does not fulfill the code requirements of three zeros and three ones. Likewise, all odd numbers of errors and many even numbers of errors are rejected. The probability is very low that during a single transmission the noise will be such as to cause two changes; i.e., a zero to a one and a one to a zero.

The three by three code employed limits this particular design to twenty commands, since all possible combinations of three zeros and three ones are used. The relation defining c, the number of commands in an n by n system is

$$c = \frac{(2n)!}{(n!)^2} \; ;$$

thus when $n = 3$,

$$c = \frac{6 \cdot 5 \cdot 4}{3!} = 20 \; .$$

This basic system may be extended to provide a greater number of commands by going to a four by four code or higher, and still retain its error sensing quality. For example, a four by four code would provide 70 commands; and a five by five, 252 commands.

GROUND STATION EQUIPMENT — ENCODER

A block diagram of the encoder is shown in Figure 1. A 1-kc input signal is fed to a shaping circuit which drives a two stage binary counter and diode gate. Zeros, ones, and sync pulses are generated continuously on three separate leads which are the inputs to a three channel gate. The output of the second stage of the binary counter (the bit rate of the system) is fed through a transistor negative AND gate to a three stage binary counter. The transistor AND gate is controlled by the output of a diode AND gate that is connected to the first and third binary stages of a divide-by-five counter. The latter obtains its input from the three stage binary counter, whose collectors are connected to a diode matrix.

Because of these interconnections, the three stage counter and diode matrix constitute an eight-position electronic stepping switch. When the transmit button is pushed, the three stage binary and the divide-by-five counter are both reset; as the divide-by-five counter is reset, the positive AND gate is opened, thereby opening the negative AND gate to allow the bit rate pulses to enter the three stage binary counter. The three stage counter produces the intervals for the eight bits of each command word, and triggers the divide-by-five counter to allow 40 bit-pulses to enter the three stage counter before the positive AND gate is closed (i.e., five eight-bit command words).

An electronic stepping switch controls the output of the three channel gate. In the first position, the three output leads are shorted and a blank is transmitted. The second position shorts all but the lead on which sync pulses are present, and allows one sync pulse to be transmitted. The third to eighth positions step the output of the six channel gate, allowing ones and zeros to be transmitted. The ten-command two-position switches are connected
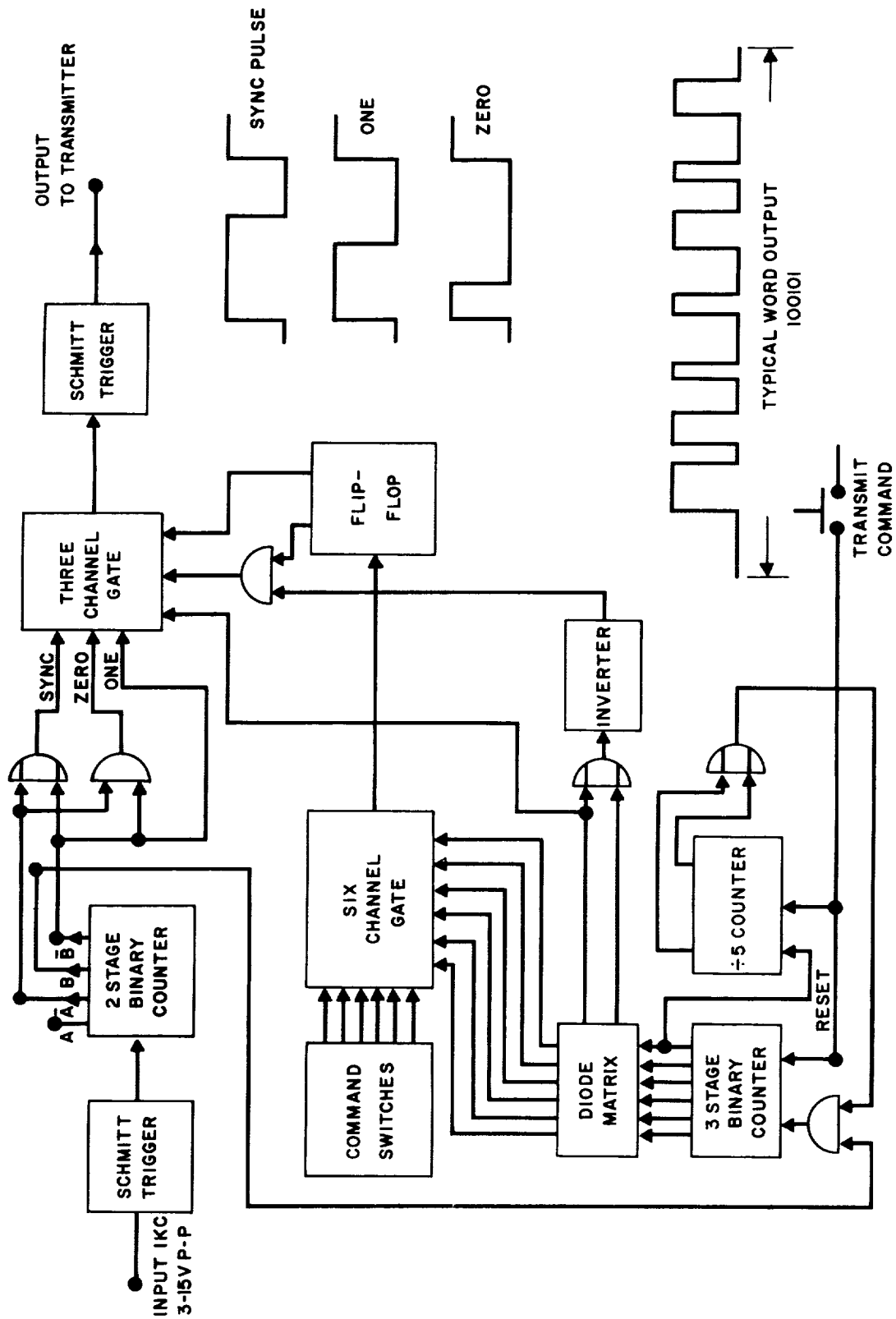
4

Figure 1 - Block diagram digital command system encoder

so that any of the twenty command words may be manually selected. Six wires, representing the six digits of the command word, connect the switches to the six channel gate. The output of the six channel gate controls the state of a binary flip-flop which in turn controls the passage of zero's or ones through the three channel gate to the output. During the first two intervals, the binary state would allow the passage of a zero; however, the AND and OR gates are present to inhibit this. This command transmission is terminated when the positive AND gate is closed.

A typical command word frame and block diagram in Figure 1 shows the blank, sync and six bit word. A complete schematic of the ground station encoder is shown in Figure 2.

AIRBORNE EQUIPMENT — DECODER

In the digital command system decoder (Figure 3), the output of a command receiver is considered to be the input and is shaped by a Schmitt trigger circuit. The leading edge of the Schmitt trigger output is used to turn on a 1-kc free running multivibrator, and is inverted to give the proper polarity signal to reset the two stage binary counter. It may be noted that both sides of the Schmitt trigger are used, thus requiring inversion to obtain the proper polarity signals; however, this was deemed necessary to distribute the load. The 1-kc multivibrator is turned on for one, two, and three milliseconds by a zero, one or sync pulse. The 1-kc bursts are fed to an AND gate controlled by the output of the Schmitt trigger and are used to trigger the two-stage binary counter. The AND gate is used to reduce the possibility of a noise burst causing the binary counter to be triggered. The trailing edge of the 1-kc pulses are used to trigger the binary counter and they cannot do so unless the Schmitt trigger is on for at least one millisecond. Noise bursts are not generally of sufficient duration to cause the Schmitt trigger to be on for one millisecond. The trailing edge of the Schmitt trigger is used as a shift pulse for the shift register, and to trigger a delay multivibrator. This delay is set long enough — approximately 28 milliseconds to allow the remainder of the decoder to reach quiescence. The outputs of the two-stage binary counter are passed to AND gates so that an output occurs for a count of two in the counter, corresponding to a one; and for a count of three, corresponding to a sync pulse. No output is obtained for a zero. These outputs are fed to the shift register where the sync pulse resets the shift register; and the ones are shifted in, thereby converting the coded command from serial to parallel form.

The collectors of the shift register transistors are connected through emitter followers to a two-section transistor matrix: the first three register stages to one matrix section, the last three to the other. The conditions of the 12 inputs to the matrix cause two of its 16 outputs to be at ground potential. Selected groups of the decoder's 20 output terminals are connected to the 8 outputs of the first matrix section by resistors, and to the other section by diodes. The interconnections are such that only one decoder output terminal
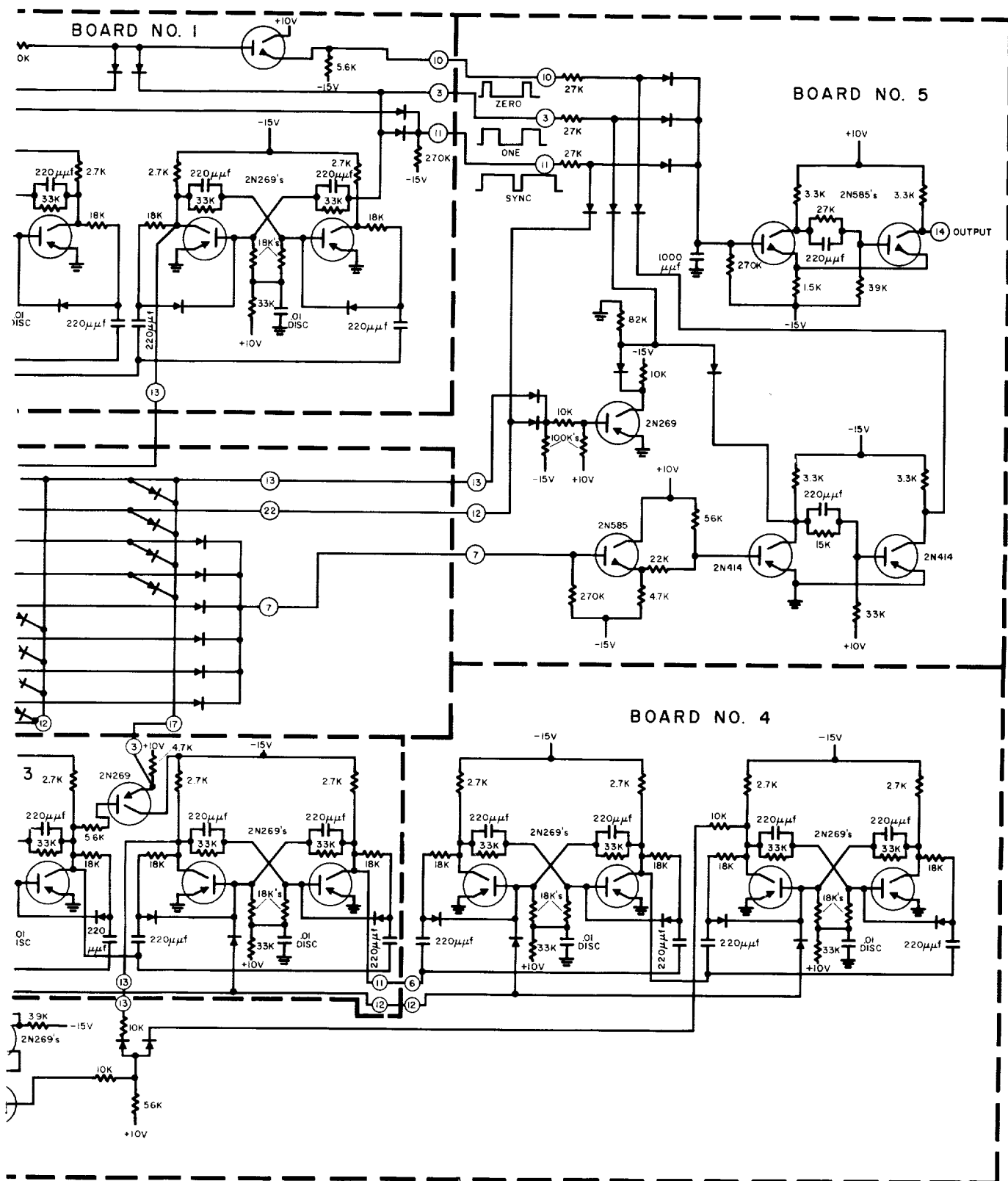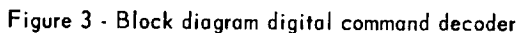
Figure 2 - Digital Command System Encoder
(ground station equipment)

D-1076

Figure 3 - Block diagram digital command decoder

is clamped to ground potential. At this time, the pulse which has been delayed by the delay multivibrator appears on a bus connected through capacitors to the decoder's 20 output leads. Owing to the bias on these leads, only the lead clamped to ground has an output pulse which rises above ground potential. Since these output leads drive circuits responding only to pulses rising above ground potential, only one output circuit of the twenty is energized.

This equipment was breadboarded in the laboratory and checked for operation within the temperature range from -40° to +70°C. The voltages employed are -6.0 volts (-12% or +65%). The standby current drain at -6 volts for 25°C is approximately 10 ma, with no appreciable change at reduced or elevated temperature. Operating current at -6 volts is 11.5 ma. The operating power is approximately 70 milliwatts for the 20 individual "on" or "off" commands, with a standby power consumption of 60 milliwatts. An attempt was made to determine the required signal-to-noise ratio. A 20-kc random noise generator was used to insert a 5 volt peak-to-peak signal in series with a 5 volt peak-to-peak input to the decoder, and the function of the system was not impaired. This test demonstrated that the system will work at signal-to-noise ratios as low as one-to-one. The use of peak-to-peak measurement is deemed allowable here because of the rectangular variable-duty-cycle character of the
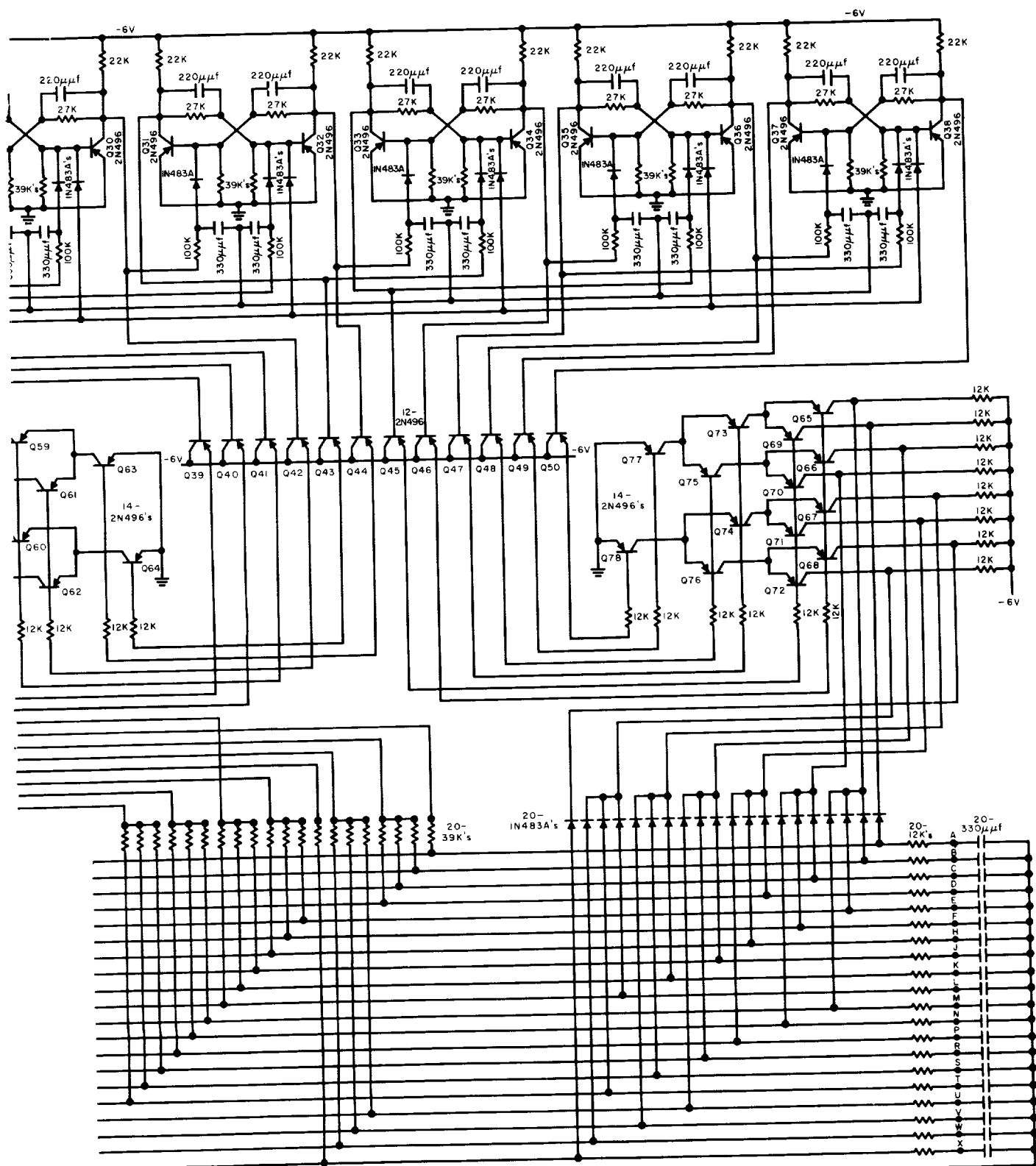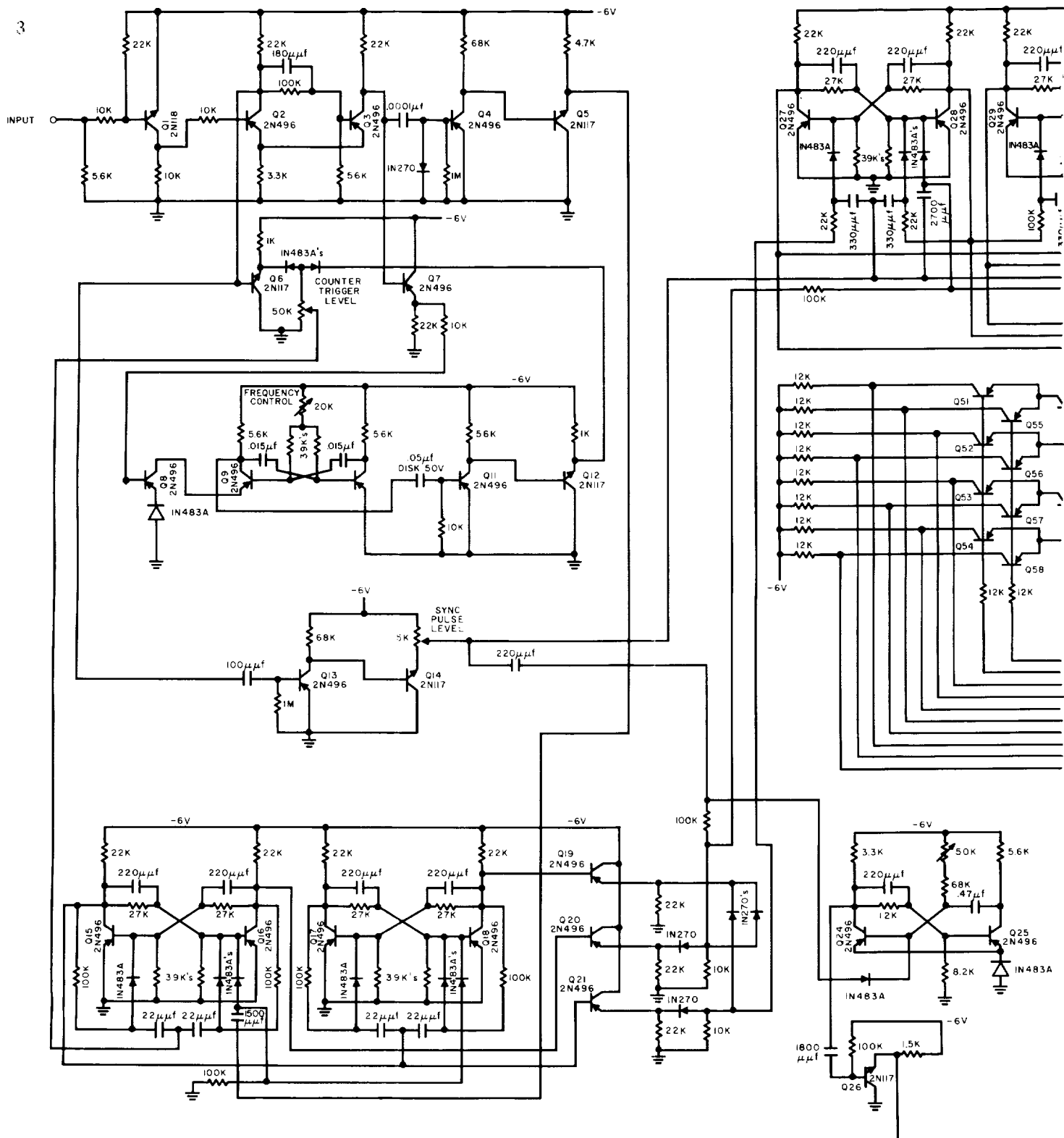
Figure 4 - Digital command decoder

D-1076

decoder input. A typical output is shown in Figure 3; and Figure 4 gives a schematic diagram of the complete airborne equipment. A list of the command codes is given in Table 1.

ACKNOWLEDGMENT

The author wishes to acknowledge the work done by Mr. Thomas P. Sifferlen, formerly of the Goddard Space Flight Center, on the design of the encoding portion of the digital command system. Mr. Sifferlen suggested the use of n by n coding to reduce noise interference and performed the design and prototype testing of the first breadboard encoder.

Table 1 - List of command codes

CHANNEL	CODE
1	111000
2	110100
3	101100
4	011100
5	110010
6	101010
7	011010
8	100110
9	010110
10	001110
11	110001
12	101001
13	011001
14	100101
15	010101
16	001101
17	100011
18	010011
19	001011
20	000111